PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

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NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
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in its capacity as elected Office

Date of mailing (day/month/year) 04 October 2000 (04.10.00)	
International application No. PCT/GB00/00323	**Applicant's or agent's file reference** P23140A/VSL/CLF/PPP
International filing date (day/month/year) 07 February 2000 (07.02.00)	**Priority date** (day/month/year) 05 February 1999 (05.02.99)
Applicant DA SILVA MARQUES, Paulo, Vicente et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   04 September 2000 (04.09.00)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

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PATENT COOPERATION TREATY

09/890694

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference P23140A/VSL/CLF/PPP	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 00/00323	International filing date *(day/month/year)* 07/02/2000	(Earliest) Priority Date *(day/month/year)* 05/02/1999
Applicant THE UNIVERSITY COURT OF THE UNIVERSITY OF et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      ☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      ☐ contained in the international application in written form.
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      ☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      ☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. ☐ **Certain claims were found unsearchable** (See Box I).
3. ☒ **Unity of invention is lacking** (see Box II).
4. With regard to the **title**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established by this Authority to read as follows:
5. With regard to the **abstract**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. 2a,2b
   ☒ as suggested by the applicant.
   ☐ because the applicant failed to suggest a figure.
   ☐ because this figure better characterizes the invention.
   ☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00323

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/132 H01S3

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 206 925 A (KAMOSHIDA TOSHIKAZU ET AL) 27 April 1993 (1993-04-27) abstract; figures 1,3,4A-4D,8 column 1, line 51 -column 2, line 10 column 3, line 1 - line 19 column 3, line 38 - line 43 column 6, line 52 -column 7, line 21 column 8, line 7 - line 58 column 8, line 60 -column 9, line 25 column 10, line 10 - line 40 column 11, line 24 - line 29 ---	1-61, 82-85
X	US 5 303 319 A (FORD CAROL M ET AL) 12 April 1994 (1994-04-12) abstract; figures 3,4 column 2, line 10 - line 38 column 3, line 29 -column 4, line 43 --- -/--	1,30, 82-85

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
10 May 2000	20.07.00

Name and mailing address of the ISA	Authorized officer
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1

Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/GB 00/00323

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 890 850 A (LUCENT TECHNOLOGIES INC) 13 January 1999 (1999-01-13) abstract; figure 9 column 7, line 18 - line 41 ---	1,30, 82-85
A	EP 0 867 985 A (TNO) 30 September 1998 (1998-09-30) abstract page 3, line 20 - line 24 page 4, line 54 -page 5, line 27 page 5; table 1 -----	1-61

1

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet(s)

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-61,82-85

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-61,82-85

An optical waveguide comprising a buffer layer including a thermally oxidised layer.

2. Claims: 62-81

A laser waveguide comprising a grating formed in the waveguide core.

International Application No

PCT/GB 00/00323

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5206925 A	27-04-1993	JP 2755471 B	20-05-1998
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		DE 4120054 A	02-01-1992
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		US 5982973 A	09-11-1999

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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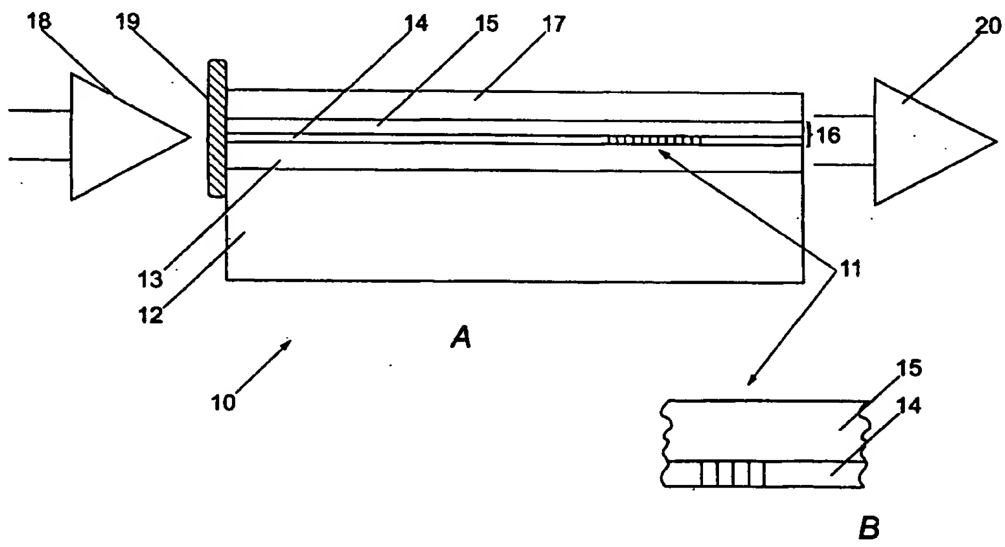
(54) Title: OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF



(57) Abstract

An optical waveguide with multiple core layers for transmitting an optical signal comprises a substrate; an intermediate layer formed on said substrate; a waveguide core formed on said intermediate layer; and an upper cladding layer embedding said waveguide core. The waveguide core comprises a first core layer formed on said intermediate layer and a second core layer formed on said first core layer. The first core layer has photosensitive properties and the second core layer has optical gain properties.

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OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF

FIELD OF THE INVENTION

This invention relates to an optical waveguide with multiple core layers and a method of fabrication thereof.

In particular, the invention relates to a doped planar waveguide with multiple core layers and which includes both active and passive components and to a method of fabricating a planar waveguide for an optical circuit in which the core is composed of layers of different materials.

BACKGROUND OF THE INVENTION

Planar waveguides can be passive devices or can include active components; for example, modulators, couplers, and switches. Planar waveguides incorporating active components are extremely advantageous as they can be used to provide integrated

optic packages which can serve as complete transmitting modules with, for example, components for amplitude or phase modulation, or multiplexing in an optical communication network.

Rare earth doped fibre amplifiers, for example erbium or neodymium doped fibre amplifiers, are known to have several advantages in optical communication networks such as high gain, low noise, high power conversion efficiency and wide spectral bandwidth. The present invention seeks to provide the same advantages in planar rare earth doped waveguides and moreover to provide a laser waveguide amplifier which can be used, for example, in an optical communication network to amplify attenuated signals.

Planar waveguide technology is important in the fabrication of lasers and optical amplifiers due to the superior stability, compact geometry of planar waveguide technology. Also, active components, for example modulators, can be integrated into the planar device.

A variety of techniques, including flame hydrolysis deposition (FHD), sputtering, plasma enhanced chemical vapour deposition (CVD) and ion-exchange can be used in the fabrication of silica-based planar waveguides doped with rare-earth ions and which display laser characteristics.

In such laser amplifying waveguides, it is desirable to obtain a high concentration of rare earth ions in order to achieve very compact and efficient devices. However, high concentrations of rare earth ions in a waveguide layer with relatively low solubility can result in the formation of clusters of rare earth ions.

The interaction between the rare earth ions in such clusters quenches the excited state required for the lasing process and thus degrades the optical amplification provided by the waveguide.

Other complications arise in the fabrication of laser waveguides for applications which require single mode transmission, narrow spectral bandwidths, and/or precise control of the lasing wavelength depend critically on their cavity type. Laser waveguides which have butt-coupled mirrors on the waveguide ends or dielectric reflection mirrors are known in the art but suffer to a greater or lesser degree from certain disadvantages; for example, low spectral selectivity.

Bragg gratings incorporated in a waveguide core can provide enhanced spectral selectivity. The fabrication of such gratings is affected by the host glass composition present in the waveguide core which determine the UV absorption band of the core material and thus its photosensitive properties. For example, if phosphorus is used as a core dopant ion it can alleviate the formation of rare earth ion clusters but has the disadvantage that it reduces the amount of absorption in the UV and thus reduces the photosensitivity of the core. If germanium is used as a core dopant ion it can increase the photosensitivity of the core but has the disadvantage of promoting rare earth cluster formation.

The introduction of a Bragg grating can be effected in a planar waveguide by a number of known methods which suffer to a greater or lesser degree from certain disadvantages. The invention provides an optical waveguide with multiple core layers which is suitable for forming a laser waveguide with a high degree of

spectral selectivity. The waveguide core combines two different types of silica based layers and these core layers obviate or mitigate the aforementioned disadvantages which arise when seeking to fabricate an in-core Bragg grating to enhance the spectral selectivity of the laser waveguide. The waveguide formed enables in-core Bragg grating formation at a range of UV wavelengths above 150 nm.

SUMMARY OF THE INVENTION

In accordance with a first aspect of the invention there is provided an optical waveguide with multiple core layers comprising: a substrate; a waveguide core formed on said substrate; and an upper cladding layer embedding said waveguide core; wherein said waveguide core comprises a first core layer and a second core layer.

Preferably, the substrate comprises silicon and/or silica and/or sapphire.

Preferably, the substrate includes an intermediate layer. The intermediate layer may include a buffer layer formed on the substrate. The buffer layer may comprise a thermally oxidised layer of the substrate.

The intermediate layer may further include a lower cladding layer formed on said buffer layer.

Preferably, the thickness of the buffer layer is in the range 5 μm to 20 μm.

The second core layer may be formed on the first core layer and said first core layer may be formed on the substrate. Alternatively, the first core layer may be

formed on the second core layer and said second core layer may be formed on the substrate. A further first core layer may be formed on the second core layer such that the first core layer sandwiches the second core layer.

Preferably, the first core layer includes a dopant to permit the first core layer to exhibit a photosensitive response. The first core layer may include silica.

Preferably, the first core layer includes a germanium oxide and/or a boron oxide. The first core layer dopant may include dopant ions. Preferably, the first core layer dopant ions include tin and/or cerium and/or sodium.

The second core layer may include a dopant to induce amplification of an optical signal transmitted through said waveguide core. The second core layer may include silica. The second core layer may include a phosphorus oxide. The second core layer dopants may include dopant ions. The second core layer dopant may include a mobile dopant.

Preferably, the second core layer dopants include a rare earth and/or a heavy metal and/or compounds of these elements. More preferably, the rare earth is Erbium or Neodymium.

Preferably, the refractive indices of the first core layer and the second core layer are substantially equal.

Preferably, the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

Preferably, the thickness of the first core layer is in the range 0.2 μm to 30 μm.

Preferably, the thickness of the second core layer is in the range 0.2 μm to 30 μm.

Preferably, the width of the waveguide core lies in the range 0.4 μm to 60 μm.

The upper cladding layer and the lower cladding layer may comprise the same material. The refractive index of the substrate and the refractive index of the upper cladding layer may be substantially equal.

In accordance with a second aspect of the invention there is provided a method of fabricating a waveguide comprising the steps of: providing a substrate; forming a waveguide core on the substrate; and forming an upper cladding layer to embed the waveguide core, wherein the waveguide core is formed from a first core layer and a second core layer.

The formation of the substrate may include the formation of an intermediate layer formed on said substrate. The formation of the intermediate layer may include the formation of a buffer layer. The buffer layer may be formed by thermally oxidising the substrate.

The formation of the intermediate layer may further include the formation of a lower cladding layer formed on said buffer layer. The formation of the lower cladding layer may include doping said lower cladding layer with a dopant. The dopant may include dopant ions.

Preferably, the second core layer is formed on the first core layer and the first core layer is formed on the substrate. Alternatively, the first core layer may be formed on the second core layer and said second core layer may be formed on the substrate.

A further first core layer may be formed on the second core layer such that the first core layer sandwiches the second core layer.

The steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer may comprise the steps of:

depositing each layer; and

at least partially consolidating each layer.

Preferably, any one of the substrate, the first core layer, the second core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of the first core layer, the second core layer or the upper cladding layer.

Preferably, the formation of the first core layer includes the doping of the first core layer with a dopant.

Preferably, the first core layer dopant permits the first core layer to exhibit a photosensitive response.

Preferably, the formation of the second core layer includes the doping of the second core layer with a dopant.

Preferably, the second core layer dopant induces amplification of an optical signal transmitted through

said waveguide core.

The formation of the substrate may include the doping of the substrate with a dopant. The dopant may include dopant ions.

Preferably, the substrate dopant includes a mobile dopant.

Preferably, said first core layer dopant ions include tin and/or cerium and/or sodium.

Preferably, said second core layer dopant ions include a rare earth and/or a heavy metal and/or compounds thereof.

Preferably, said rare earth is Erbium and/or Neodymium.

Preferably, the concentration of the first core layer dopant is selectively controlled during the formation of the first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

Preferably, the concentrations of the first core layer dopant and second core layer dopant are controlled to give a refractive index for the waveguide core which differs from that of the substrate layer by at least 0.05%.

The lower cladding layer and said buffer layer may be formed substantially in the same step. At least one of the substrate, the first core layer, the second core

layer, and the upper cladding layer may be deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process. The Chemical Vapour Deposition process may be a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

Preferably, the consolidation is by fusing using a Flame Hydrolysis Deposition burner. Alternatively, the consolidation may be by fusing in a furnace.

The step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer may be performed simultaneously. The waveguide core may be formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process. The dry etching technique may comprise a reactive ion etching process and/or a plasma etching process and/or an ion milling process.

The waveguide core formed from the first core layer and the second core layer may be square or rectangular in cross-section.

In accordance with a third aspect of the invention there is provided a laser waveguide with multiple core layers comprising a waveguide according to the first aspect of the invention, the laser waveguide further comprising:

at least one grating formed in said waveguide core.

Preferably, the laser waveguide further comprises at least one optical interference mirror.

More preferably, the optical interference mirror is provided at the input of the waveguide. The interference mirror may be butt-coupled to or directly deposited at the input of the waveguide.

The laser waveguide may include two mirrors and a grating. Alternatively, the laser waveguide may include one mirror and two gratings. Alternatively, the laser waveguide may include three gratings. The grating formed may be a Bragg grating. The grating may form an output coupler for said laser waveguide.

The laser waveguide may further comprise an optical interference mirror butt coupled to or directly deposited at the output of the waveguide.

In accordance with a fourth aspect of the invention there is provided method of fabricating a laser waveguide, comprising forming a waveguide according to the method of the second aspect of the invention, the method of fabricating the laser waveguide further including the steps of:

forming at least one grating in said waveguide core.

The method may further include the step of attaching at least one optical interference mirror to the waveguide.

The optical interference mirror may be attached to an input of the waveguide.

The grating may be formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide. The mask may be a quartz mask. The grating may be formed using a using an interference

side writing technique. The grating may be formed using a direct writing technique. The grating formed may be a Bragg grating.

Preferably, in the above method, the optical interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

The method may further comprise the step of attaching a second optical interference mirror to the output of the waveguide.

DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figs. 1A to 1C are schematic cross-sectional diagrams of a waveguide with multiple core layers during various stages of fabrication.

Fig. 2A is a schematic representation of a laser waveguide formed from the waveguide shown in Figs. 1A to 1C; and

Fig. 2B is a detail, to an enlarged scale, of the structure shown in Fig. 2A.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, Figs. 1A to 1C illustrate schematically stages in the fabrication of a waveguide with a multi-layered core according to the invention.

Referring now to Fig. 1A, there is illustrated a waveguide 1 which is fabricated from a substrate 2. The substrate 2 comprises a silicon wafer. However, other suitable substrates including silica and sapphire, may be used.

A silica buffer layer 3, comprising a thermally oxidised layer of the substrate 2, is formed on the substrate 2. The thickness of the buffer layer 3 is 15 μm which lies in a preferred range of 5 μm to 20 μm.

A suitable method, for example, a flame hydrolysis deposition (FHD) method, is used to deposit a first core layer 4 on top of the buffer layer 3. The thickness of the first core layer 4 is 2 μm which lies in a preferred range of 0.2 μm to 30 μm.

The material included in the first core layer 4 provides a high photosensitive response to an optical signal. In a preferred embodiment, the first core layer 4 includes a high concentration of Germanium dopant, for example 17 %wt, co-doped with Boron, for example 5 %wt. Other dopant ions can be included, or a mixture of dopant ions, for example, tin, cerium, and/or sodium.

The dopant and co-dopants are introduced during the deposition of the first core layer 4. The Germanium dopant induces a high photosensitive response and the Boron co-dopant lowers the refractive index induced by the high level of Germanium in the first core layer 4. The concentrations of the dopant and co-dopant are adjusted to 17% wt and 5% wt to give a difference between the refractive index of the first core layer 4 and the refractive index of the buffer layer 3 of 0.75% which lies in a preferred range of 0.05% to 2.0% .

The first core layer 4 is then consolidated by a suitable method, for example by a second pass of the FHD burner or by consolidating the waveguide 1 in an electrical furnace.

Fig. 1B shows a further stage in the fabrication of the waveguide 1 in which a second core layer 5 is formed on the first core layer 4.

The second core layer 5 is deposited on the first core layer 4 using a suitable method, for example FHD, and is then suitably consolidated, for example, in an electrical furnace.

The second core layer 5 is doped with rare earth dopant ions, for example Er^{+3}, using an aerosol doping technique, and co-doped, for example, with Phosphorus during the deposition of the second core layer 5. The thickness of the second core layer 5 is $4\mu m$, which lies in the range of $0.2\mu m$ to $30\mu m$.

Alternative methods can be used to dope the second core layer 5 such as solution doping. Preferably, the dopant and co-dopant are simultaneously introduced in a controlled manner during the deposition of the second core layer 5. The concentrations of the dopant and co-dopant can be controlled so that the second core layer 5 provides the desired signal gain for optical signals propagating through the waveguide and also to ensure that the refractive index of the second core layer 5 is matched to the refractive index of the first core layer 4. In this embodiment, the indices are substantially matched. Alternatively, the first core layer 4 and the second core layer 5 can be subjected to a further process, for example, UV trimming, to effect matching of their refractive indices.

The photosensitive response of the first core layer 4 in combination with the optical signal gain of the second core layer 5 effect the overall level of optical signal amplification provided by the waveguide 1.

A waveguide core 6 is then formed from the first core layer 4 and the second core layer 5 by using a suitable method, for example conventional photolithographic and/or reactive ion etching (RIE) methods. A portion of the second core layer 5 is suitably masked and the unwanted portions of the second core layer 5 and the underlying first core layer 4 are etched away to leave the waveguide core 6. The overall dimensions of the waveguide core 6 formed are 6μm x 6μm which is in a preferred range of 0.4μm x 0.4μm to 60 μm x 60μm.

The co-dopant, here Boron, in the first core layer 4 reduce the refractive index of the waveguide core 6 and enable single mode operation even for large waveguide cores, for example waveguide cores whose dimensions are in the range of 0.4μm x 0.4μm to 60 μm x 60μm. The co-dopant in the first core layer 4 can also provide other advantages such as enabling higher refractive index changes to occur during later stages of fabrication of a waveguide with multiple core layers.

The first core layer 4 effectively can reduce the optical signal gain provided by the second core layer 5. It is thus advantageous for the first core layer 4 to be as photosensitive as possible in particular as the refractive index modulation no longer occurs over the entire volume of the waveguide core 6.

Fig. 1C shows a further stage in the fabrication of the waveguide. An upper cladding layer 7 is deposited on the waveguide core 6 using an FHD method. The upper

cladding layer 7 embeds the waveguide core 6. The upper cladding layer 7 is doped during deposition, for example with Phosphorus and Boron, to adjust its refractive index until the refractive index of the upper cladding layer 7 matches the refractive index of the buffer layer 3. The upper cladding layer 7 is then consolidated, for example in an electrical furnace.

In a second preferred embodiment of the invention, a lower cladding layer is formed on top of the buffer layer 3 before the first core layer 4 is deposited and in which the level of dopant in the upper cladding layer 7 is adjusted until the refractive index of the upper cladding layer 7 matches that of the lower cladding layer. The lower cladding layer can be deposited and consolidated using the same techniques as the upper cladding layer 7.

In an alternative layer structure the first core layer 4 may be deposited on top of the second core layer 5 or respective first core layers 4 may be provided both below and on top of the second core layer 5. The core layer 5 is then sandwiched between two photo-sensitive first core layers 4 increasing the coupling coefficient of the device.

It is possible also, for certain applications, to dope the photo-sensitive first core layer 4 with a small amount of rare earth ions.

Referring now to Figs. 2A and 2B of the drawings, there is shown a schematic diagram of laser waveguide according to the invention. Figs. 2A and 2B show a cross-section parallel to the longitudinal axis of the laser waveguide core, such that the waveguide core is seen only in profile.

Fig. 2A shows a planar laser waveguide 10 incorporating a Bragg grating 11. The laser waveguide 10 includes a silicon substrate layer 12 and a silica buffer layer 13 comprising a thermally oxidised layer of the substrate 12. The buffer layer 13 is formed on the substrate layer 12.

Fig. 2B is an enlarged view of a section of Fig. 2A. A first core layer 14 is deposited and consolidated on the buffer layer 13 and second core layer 15 is deposited and consolidated on the first core layer 14 using the techniques described above for the deposition and consolidation of first and second core layers 4 and 5 in the waveguide 1. The first core layer 14 can alternatively be formed on an lower cladding layer (not shown) formed on buffer layer 13.

The second core layer 15 is doped with neodymium instead of the erbium used as a dopant in the second core layer 5. Fig. 2A represents a cross-section through the laser waveguide 10 parallel to the direction of light propagation through the waveguide 10 (i.e., normal to the cross-sectional plane through the waveguide shown in Fig. 1C). The waveguide core 16 is formed from said first core layer 14 and said second core layer 15 using the same technique described above for the formation of the first core layer 4 and the second core layer 15.

An upper cladding layer 17 is then deposited on the second core layer 15 and the grating 11. The upper cladding layer 17 is deposited and consolidated using the same methods as described above for the deposition and consolidation of the upper cladding layer 7 in the fabrication of waveguide 1.

The laser cavity of the laser waveguide 10 is fabricated by writing the Bragg grating 11 into a generally central portion of the first core layer 14 and the second core layer 15. Conventionally, the Bragg grating 11 may be written using a KrF excimer laser operating at 248 nm through a quartz phase mask deposited on top of the upper cladding layer.

An input 18 of the laser waveguide 10 provides an optical signal at a pump wavelength to the laser waveguide 10. An optical interference mirror 19 butt-coupled to the input end 18 of the laser waveguide 10 has a high reflectivity (R_{sig} = 99.9%) around the maxima of the desired output wavelength and has a high transmittance at the pump wavelength (T_{pump} > 95%). The grating 11 forms an output coupler at the output 20 of the laser waveguide 10.

The grating 11 is designed for use at 1050 nm and the reflectivity of the grating 11 formed saturates at 80%. The phase mask used to form the grating 11 has a pitch of 720 nm. In other embodiments, however, it is possible to form gratings 11 which can be used at a wavelength in the range of 500 nm to 2100 nm by using suitable phase masks.

In another embodiment of a laser waveguide, a grating 11 can be provided at both the input 18 and the output 20 of the laser waveguide 10, preferably with both gratings having substantially the same Bragg wavelength thus providing a distributed Bragg reflection laser (DBR).

In yet another embodiment, a distributed feedback laser (DFB) can also be formed by having a grating extending

along the length of the gain cavity formed by the core layer 5.

Further, a multicavity laser can be formed by butt-coupling another mirror to the output end of the laser waveguide 10. These external mirrors can be bulk mirror butt-coupled or mirrors directly deposited on the ends of the waveguide. A multiple wavelength laser can be provided by photoimprinting a sampled grating in the waveguide core, with precise control of channel spacing. Additionally, a multiple wavelength laser can be achieved by exposing the same core area to very similar UV patterns, with each exposure determining each one of the emission wavelengths of the superimposed Bragg gratings. An additional grating can be defined to provide gain equalisation for the several wavelengths.

Thus, a multicavity laser can be constructed by using two mirrors and a grating, one mirror and two gratings, or indeed three gratings.

Still further, in a different application, for example, optical amplifiers, a grating can also be formed on the first core layer 4 to act as a "tap" to flatten optical gain spectra.

While several embodiments of the present invention have been described and illustrated, it will be apparent to those skilled in the art once given this disclosure that various modifications, changes, improvements and variations may be made without departing from the spirit or scope of this invention.

Claims:-

1. An optical waveguide with multiple core layers for transmitting an optical signal, the waveguide including:

a substrate;

a waveguide core formed on said substrate; and

an upper cladding layer embedding said waveguide core;

wherein said waveguide core comprises a first core layer and a second core layer.

2. A waveguide as claimed in any preceding claim, wherein the substrate comprises silicon and/or silica and/or sapphire.

3. A waveguide as claimed in either preceding claim, wherein the substrate includes an intermediate layer.

4. A waveguide as claimed in Claim 3, and wherein the intermediate layer includes a buffer layer formed on the substrate.

5. A waveguide as claimed in Claim 4, wherein said buffer layer comprises a thermally oxidised layer of the substrate.

6. A waveguide as claimed in any one of Claims 4 or 5, wherein the intermediate layer further includes a lower cladding layer formed on said buffer layer.

7. A waveguide as claimed in any one of Claims 4 to 6, wherein the thickness of the buffer layer is in the range 5 μm to 20 μm.

8. A waveguide as claimed in any preceding claim, wherein the second core layer is formed on the first core layer and said first core layer is formed on the substrate.

9. A waveguide as claimed in any one of Claims 1 to 7, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

10. A waveguide as claimed in Claim 8, wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

11. An optical waveguide as claimed in any preceding claim, wherein the first core layer includes a dopant to permit the first core layer to exhibit a photosensitive response.

12. A waveguide as claimed in any preceding claim, wherein the first core layer includes silica.

13. A waveguide as claimed in any preceding claim, wherein the first core layer includes a germanium oxide and/or a boron oxide.

14. A waveguide as claimed in of Claims 11 to 13, wherein the first core layer dopant includes dopant ions.

15. A waveguide as claimed in Claim 14, wherein the first core layer dopant ions include tin and/or cerium and/or sodium.

16. An optical waveguide as claimed in any preceding

claim, wherein the second core layer includes a dopant to induce amplification of an optical signal transmitted through said waveguide core.

17. A waveguide as claimed in any preceding claim, wherein the second core layer includes silica.

18. A waveguide as claimed in any preceding claim, wherein the second core layer includes a phosphorus oxide.

19. A waveguide as claimed in any of Claims 16 to 18, wherein the second core layer dopants include dopant ions.

20. A waveguide as claimed in Claim 19, wherein the second core layer dopant includes a mobile dopant.

21. A waveguide as claimed in one of Claims 17 to 20, wherein the second core layer dopants include a rare earth and/or a heavy metal and/or compounds of these elements.

22. A waveguide as claimed in Claim 21, wherein the rare earth is Erbium or Neodymium.

23. A waveguide as claimed in any preceding claim, wherein the refractive indices of the first core layer and the second core layer are substantially equal.

24. A waveguide as claimed in any preceding claim, wherein the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

25. A waveguide as claimed in any preceding claim, wherein the thickness of the first core layer is in the

range 0.2 μm to 30 μm.

26. A waveguide as claimed in any preceding claim, wherein the thickness of the second core layer is in the range 0.2 μm to 30 μm.

27. A waveguide as claimed in Claim 25, wherein the width of the waveguide core lies in the range 0.4 μm to 60 μm.

28. A waveguide as claimed in any one of Claims 6 to 27, wherein the upper cladding layer and the lower cladding layer comprise the same material.

29. A waveguide as claimed in any preceding claim, wherein the refractive index of the substrate and the refractive index of the upper cladding layer are substantially equal.

30. A method of fabricating a waveguide comprising the steps of:

providing a substrate;

forming a waveguide core on the substrate; and

forming an upper cladding layer to embed the waveguide core, wherein the waveguide core is formed from a first core layer and a second core layer.

31. A method as claimed in Claim 30, wherein the formation of the substrate includes the formation of an intermediate layer formed on said substrate.

32. A method as claimed in Claim 31, wherein the formation of the intermediate layer includes the formation of a buffer layer.

33. A method as claimed in Claim 33, wherein the

buffer layer is formed by thermally oxidising the substrate.

34. A method as claimed in any of Claims 32 to 33, wherein the formation of the intermediate layer further includes the formation of a lower cladding layer formed on said buffer layer.

35. A method as claimed in Claim 34, wherein the formation of the lower cladding layer includes doping said lower cladding layer with a dopant.

36. A method as claimed in Claim 34, wherein the dopant includes dopant ions.

37. A method as claimed in any of Claims 30 to 36, wherein the second core layer is formed on the first core layer and wherein the first core layer is formed on the substrate.

38. A waveguide as claimed in any of Claims 30 to 37, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

39. A waveguide as claimed in Claim 37, wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

40. A method as claimed in any of Claims 30 to 39, wherein the steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer comprise the steps of:

depositing each layer; and

at least partially consolidating each layer.

41. A method as claimed in Claim 40, wherein any one of the substrate, the first core layer, the second core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of the first core layer, the second core layer or the upper cladding layer.

42. A method as claimed in any of Claims 30 to 41, wherein the formation of the first core layer includes the doping of the first core layer with a dopant.

43. A method as claimed in Claim 42, wherein the first core layer dopant permits the first core layer to exhibit a photosensitive response.

44. A method as claimed in any of Claims 30 to 43, wherein the formation of the second core layer includes the doping of the second core layer with a dopant.

45. A method as claimed in any of Claims 30 to 44, wherein the second core layer dopant induces amplification of an optical signal transmitted through said waveguide core.

46. A method as claimed in any of Claims 30 to 45, wherein the formation of the substrate includes the doping of the substrate with a dopant.

47. A method as claimed in any one of Claims 42 to 46, wherein the dopant includes dopant ions.

48. A method as claimed in Claim 47, wherein the substrate dopant includes a mobile dopant.

49. A method as claimed in any of Claims 47 to 48,

wherein said first core layer dopant ions include tin and/or cerium and/or sodium.

50. A method as claimed in any of Claims 47 to 49, wherein said second core layer dopant ions include a rare earth and/or a heavy metal and/or compounds thereof.

51. A method as claimed in Claim 50, wherein said rare earth is Erbium and/or Neodymium.

52. A method as claimed in any of Claims 42 to 51, wherein the concentration of the first core layer dopant is selectively controlled during the formation of the first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

53. A method as claimed in Claim 52, wherein the concentrations of the first core layer dopant and second core layer dopant are controlled to give a refractive index for the waveguide core which differs from that of the substrate layer by at least 0.05%.

54. A method as claimed in any of Claim 34, wherein said lower cladding layer and said buffer layer are formed substantially in the same step.

55. A method as claimed in any of Claims 40 to 54, wherein at least one of the substrate, the first core layer, the second core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

56. A method as claimed in Claim 55, wherein the Chemical Vapour Deposition process is a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

57. A method as claimed in any of Claims 40 to 56, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

58. A method as claimed in any of Claims 40 to 57, wherein the consolidation is by fusing in a furnace.

59. A method as claimed in either of Claims 57 or 58, wherein the step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer are performed simultaneously.

60. A method as claimed in any of Claims 30 to 59, wherein the waveguide core is formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process.

61. A method as claimed in Claim 60, wherein the dry etching technique comprises a reactive ion etching process and/or a plasma etching process and/or an ion milling process.

62. A method as claimed in any of Claims 30 to 61, wherein the waveguide core formed from the first core layer and the second core layer is square or rectangular in cross-section.

63. A laser waveguide with multiple core layers for transmitting an optical signal, the laser waveguide comprising a waveguide as claimed in any one of claims

1 to 29, the laser waveguide further comprising:
at least one grating formed in said waveguide core.

64. A laser waveguide as claimed in Claim 63, wherein the laser waveguide further comprises at least one optical interference mirror.

65. A laser waveguide as claimed in Claim 64, wherein the optical interference mirror is provided at the input of the waveguide.

66. A laser waveguide as claimed in Claim 65, wherein the interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

67. A laser waveguide as claimed in any of Claims 63 to 66, wherein the laser waveguide includes two mirrors and a grating.

68. A laser waveguide as claimed in any of Claims 63 to 66, wherein the laser waveguide includes one mirror and two gratings.

69. A laser waveguide as claimed in Claim 63, wherein the laser waveguide includes three gratings.

70. A laser waveguide as claimed in any of Claims 63 to 69, wherein the grating formed is a Bragg grating.

71. A laser waveguide as claimed in any one of Claims 63 to 70, wherein said grating forms an output coupler for said laser waveguide.

72. A laser waveguide as claimed in any one of Claims 63 to 71 further comprising an optical interference

mirror butt coupled to or directly deposited at the output of the waveguide.

73. A method of fabricating a laser waveguide, comprising forming a waveguide according to a method as claimed in any of claims 30 to 62, the method of fabricating the laser waveguide further including the steps of:

forming at least one grating in said waveguide core.

74. A method as claimed in Claim 73, further including the step of attaching at least one optical interference mirror to the waveguide.

75. A method as claimed in Claim 74, wherein the optical interference mirror is attached to an input of the waveguide.

76. A method as claimed in Claims 73 to 75, wherein the grating is formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide.

77. A method as claimed in Claim 76, wherein said mask is a quartz mask.

78. A method as claimed in Claim 73 to 75, wherein the grating is formed using a using an interference side writing technique.

79. A method as claimed in any one of Claims 73 to 75, wherein the grating is formed using a direct writing technique.

80. A method as claimed in any one of Claims 73 to 79, wherein the grating formed is a Bragg grating.

81. A method as claimed in any one of Claims 74 to 80, wherein the optical interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

82. A method as claimed in any one of Claims 73 to 80, further comprising the step of attaching a second optical interference mirror to the output of the waveguide.

83. A waveguide substantially as described herein and with reference to Figs. 1A to 1C of the accompanying drawings.

84. A laser waveguide substantially as described herein and with reference to Figs. 2A and 2B of the accompanying drawings.

85. A method of fabricating a waveguide with multiple core layers substantially as described herein and with reference to Figs. 1A to 1C of the accompanying drawings.

86. A method of fabricating a laser waveguide with multiple core layers substantially as described herein and with reference to Figs. 2A and 2B of the accompanying drawings.

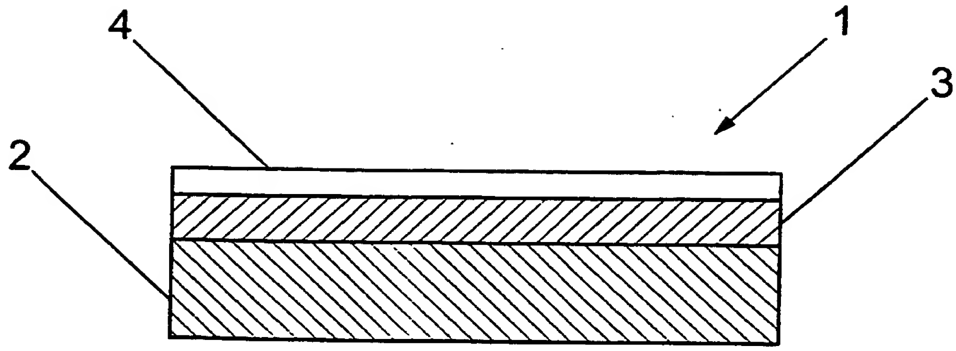

Fig. 1A

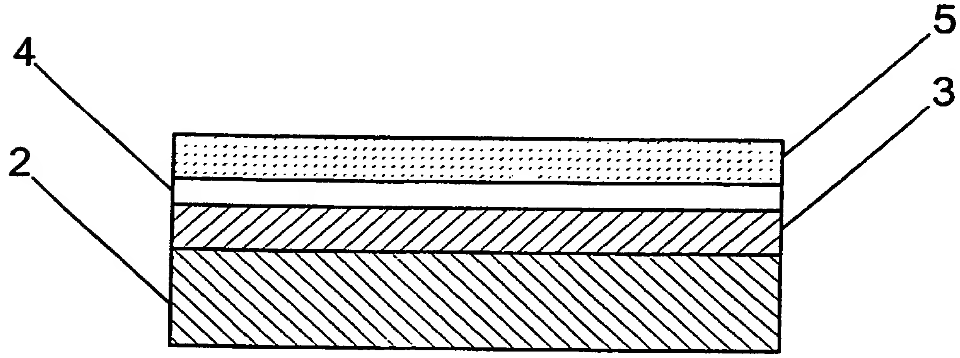

Fig. 1B

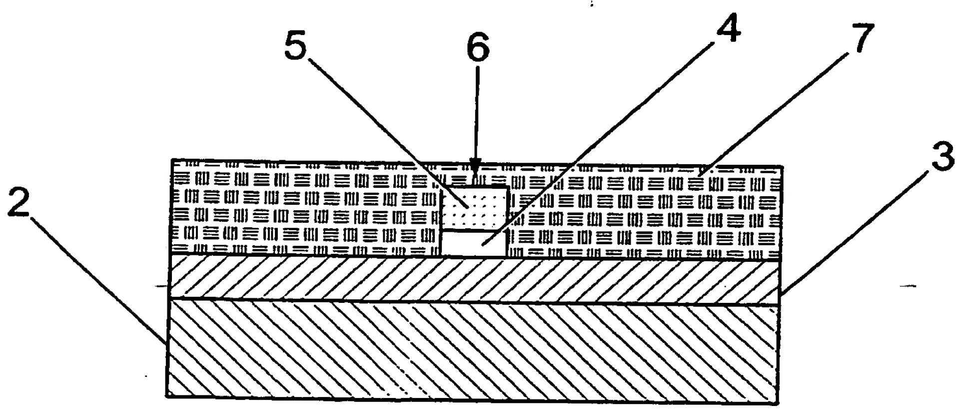

Fig. 1C

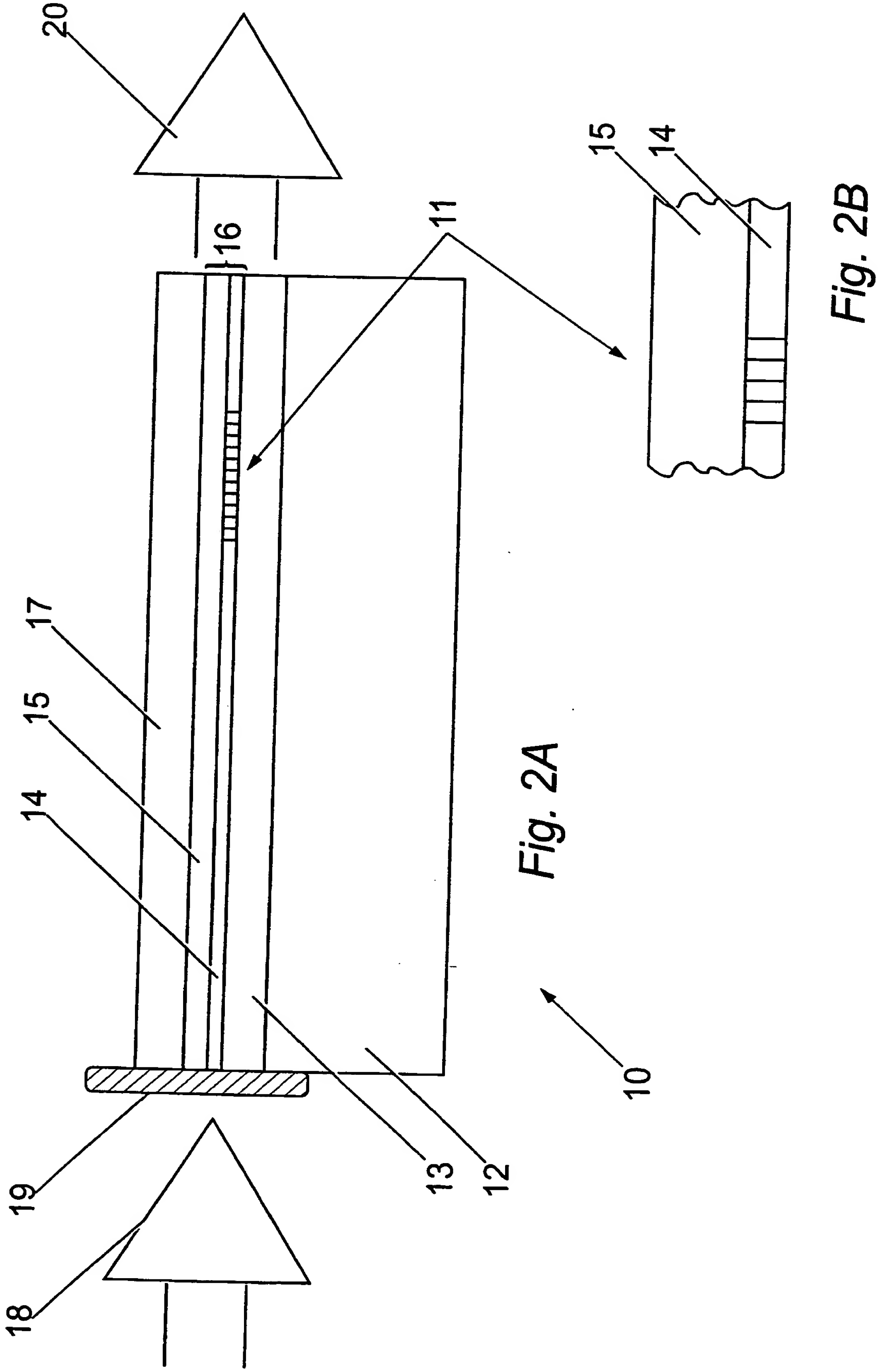

Fig. 2A

Fig. 2B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/[illegible]00/00323

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/132 H01S3/063

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 206 925 A (KAMOSHIDA TOSHIKAZU ET AL) 27 April 1993 (1993-04-27) abstract; figures 1,3,4A-4D,8 column 1, line 51 -column 2, line 10 column 3, line 1 - line 19 column 3, line 38 - line 43 column 6, line 52 -column 7, line 21 column 8, line 7 - line 58 column 8, line 60 -column 9, line 25 column 10, line 10 - line 40 column 11, line 24 - line 29 ---	1-61, 82-85
X	US 5 303 319 A (FORD CAROL M ET AL) 12 April 1994 (1994-04-12) abstract; figures 3,4 column 2, line 10 - line 38 column 3, line 29 -column 4, line 43 ---	1,30, 82-85
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 May 2000	20.07.00

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
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Jakober, F

1

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 890 850 A (LUCENT TECHNOLOGIES INC) 13 January 1999 (1999-01-13) abstract; figure 9 column 7, line 18 - line 41 ---	1,30, 82-85
A	EP 0 867 985 A (TNO) 30 September 1998 (1998-09-30) abstract page 3, line 20 - line 24 page 4, line 54 -page 5, line 27 page 5; table 1 -----	1-61

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/00323

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet(s)

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-61,82-85

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

International Application No. PCT/GB 00/00323

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210
1. Claims: 1-61,82-85 An optical waveguide comprising a buffer layer including a thermally oxidised layer. 2. Claims: 62-81 A laser waveguide comprising a grating formed in the waveguide core.

INTERNATIONAL SEARCH REPORT

Informati[redacted]atent family members

International [redacted] Application No
PCT/[redacted]00/00323

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5206925	A	27-04-1993	JP	2755471	B	20-05-1998
			JP	4060618	A	26-02-1992
			CA	2040527	A,C	30-12-1991
			DE	4120054	A	02-01-1992
			GB	2245984	A,B	15-01-1992
US 5303319	A	12-04-1994	NONE			
EP 0890850	A	13-01-1999	US	6003222	A	21-12-1999
			JP	11084156	A	26-03-1999
EP 0867985	A	30-09-1998	JP	11038242	A	12-02-1999
			US	5982973	A	09-11-1999

09/890694

14

PATENT COOPERATION TREATY

PCT

REC'D 29 MAY 2001	
WIPO	PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P23140A/RWA/JMK/PPP	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/00323	International filing date *(day/month/year)* 07/02/2000	Priority date *(day/month/year)* 05/02/1999
International Patent Classification (IPC) or national classification and IPC G02B6/132		
Applicant THE UNIVERSITY COURT OF THE UNIVERSITY OF et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 12 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand 04/09/2000	Date of completion of this report 25.05.2001
Name and mailing address of the international preliminary examining authority: European Patent Office - P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Tx: 31 651 epo nl Fax: +31 70 340 - 3016	Authorized officer Jakober, F Telephone No. +31 70 340 3652

INTERNATIONAL PRELIMINARY
EXAMINATION REPORT

International application No. PCT/GB00/00323

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, pages:

1-18	as originally filed	

Claims, No.:

1-85	with telefax of	08.03.2001

Drawings, sheets:

1/2,2/2	as originally filed	

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application.

☒ claims Nos. 62-81.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☐ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. are so unclear that no meaningful opinion could be formed (*specify*):

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☒ no international search report has been established for the said claims Nos. 62-81.

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

☐ the written form has not been furnished or does not comply with the standard.

☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N) Yes: Claims 2-29,31-61

	No:	Claims	1,30
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-61
Industrial applicability (IA)	Yes:	Claims	1-61
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Reference is made to the following documents:

D1: US-A-5206925
D2: US-A-5303319
D3: EP-A-0890850
D4: EP-A-0867985

1. None of the independent claims define novel subject-matter. Hence, the application cannot be considered to satisfy the criteria set forth in Art. 33 PCT.

2. Claim 1:
Document D1 discloses in figure 4(d) and the corresponding description an optical waveguide with multiple core layers including
- a substrate (1),
- a waveguide core (3),
- an upper cladding layer embedding said waveguide core (9),
- wherein said waveguide core comprises a first core layer (7 or 8) including a dopant (Ge) permitting the core layer to exhibit a photosensitive response (it is well known that Ge is a photosensitive material) and a second core layer (4) including a dopant to induce amplification (rare earth).

Thus, the claimed waveguide is not novel within the meaning of Art. 33 PCT, since for each feature of claim 1 a counterpart can be found in document D1.

3. Claim 30:
Document D1 discloses in figures 4(a) to 4(d) and the corresponding description a method of fabricating a waveguide comprising the steps of:
- providing a substrate (1),
- forming a waveguide core (3),
- forming an upper cladding layer to embed said waveguide core (9),
- wherein said waveguide core is formed from a first core layer (7 or 8) including a

dopant (Ge) permiting the core layer to exhibit a photosensitive response (it is well known that Ge is a photosensitive material) and a second core layer (4) including a dopant to induce amplification (rare earth).

In view of the above, claim 30 cannot be considered to define novel subject-matter, since for each feature of claim 30 a counterpart can be found in document D1.

4. The dependent claims do not define subject matter which is inventive, since their structural features are either known from D1 or obvious modifications (see passages cited in the international search report).

Re Item VII

Certain defects in the international application

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the document D1 is not mentioned in the description, nor is this document identified therein.

Re Item VIII

Certain observations on the international application

1. Claims 82 to 85 only contain references to the description and the drawings. They are therefore not clear in the meaning of Art. 6 PCT. According to Rule 6.2(a) PCT, claims should not contain such references except where absolutely necessary, which is not the case here. They should therefore have been deleted.

2. The "spirit clause" (page 18, last paragraph) should have been deleted as its presence in the description serves only to cast unnecessary doubt upon the intended scope of the claims.

Claims

1. An optical waveguide with multiple core layers for transmitting an optical signal, the waveguide including:
a substrate;
a waveguide core formed on the substrate and comprising a first core layer and a second core layer;
an upper cladding layer embedding said waveguide core;
wherein the first core layer includes a dopant to permit the first core layer to exhibit a photosensitive response, and the second core layer includes a dopant to induce amplification of an optical signal transmitted through said waveguide core.

2. An optical waveguide according to Claim 1, wherein the first core layer includes a germanium oxide to permit the first core layer to exhibit a photosensitive response.

3. An optical waveguide according to Claim 2, wherein the first core layer further includes a boron oxide.

4. A waveguide as claimed in any preceding claim, wherein the substrate comprises silicon and/or silica and/or sapphire.

5. A waveguide as claimed in any preceding claim, wherein the substrate includes an intermediate layer.

6. A waveguide as claimed in Claim 5, wherein the intermediate layer includes a buffer layer formed on the substrate.

7. A waveguide as claimed in Claim 6, wherein said buffer layer comprises a thermally oxidised layer of the substrate.

8. A waveguide as claimed in Claim 6 or Claim 7, wherein the intermediate layer further includes a lower cladding layer formed on said buffer layer.

9. A waveguide as claimed in any of Claims 6 to 8, wherein the thickness of the buffer layer is in the range 5 m to 20 m.

10. A waveguide as claimed in any preceding claim, wherein the second core layer is formed on the first core layer and said first core layer is formed on the substrate.

11. A waveguide as claimed in any of Claims 1 to 9, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

12. A waveguide as claimed in Claim 10, wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

13. A waveguide as claimed in any preceding claim, wherein the first core layer includes silica.

14. A waveguide as claimed in any preceding claim, wherein the first core layer dopant includes dopant ions.

15. A waveguide as claimed in Claim 14, wherein the first core layer dopant ions include tin and/or cerium and/or sodium.

16. A waveguide as claimed in any preceding claim, wherein the second core layer includes silica.

17. A waveguide as claimed in any preceding claim, wherein the second core layer includes a phosphorus oxide.

18. A waveguide as claimed in any preceding claim, wherein the second core layer dopant includes dopant ions.

19. A waveguide as claimed in Claim 18, wherein the second core layer dopant includes a mobile dopant.

20. A waveguide as claimed in any of Claims 16 to 19, wherein the second core layer dopant includes a rare earth and/or a heavy metal and/or compounds of these elements.

21. A waveguide as claimed in Claim 20, wherein the rare earth is Erbium or Neodymium.

22. A waveguide as claimed in any preceding claim, wherein the refractive indices of the first core layer and the second core layer are substantially equal.

23. A waveguide as claimed in any preceding claim, wherein the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

24. A waveguide as claimed in any preceding claim, wherein the thickness of the first core layer is in the range 0.2 m to 30 m.

25. A waveguide as claimed in any preceding claim, wherein the thickness of the second core layer is in the range 0.2 m to 30 m.

26. A waveguide as claimed in Claim 24, wherein the width of the waveguide core lies in the range 0.4 m to 60 m.

27. A waveguide as claimed in any of Claims 8 to 26, wherein the upper cladding layer and the lower cladding layer comprise the same material.

28. A waveguide as claimed in any preceding claim, wherein the refractive index of the substrate and the refractive index of the upper cladding layer are substantially equal.

29. An optical waveguide according to any of Claims 1 to 28, wherein the first core layer includes at least 17% wt germanium dopant.

30. A method of fabricating a waveguide comprising the steps of:

providing a substrate;

forming a waveguide core on the substrate, the waveguide core comprising a first core layer and a second core layer;

forming an upper cladding layer to embed the waveguide core;

wherein the formation of the first core layer includes the doping of the first core layer with a dopant for permitting the first core layer to exhibit a photosensitive response, and the formation of the second core layer includes the doping of the second core layer with a dopant for inducing amplification of an optical signal transmitted through said waveguide core.

31. A method according to Claim 30, wherein the dopant used to permit the first core layer to exhibit a photosensitive response is a germanium dopant.

32. A method according to Claim 31, wherein the first core layer is co-doped with a boron dopant.

33. A method as claimed in any of Claims 30 to 32, wherein the formation of the substrate includes the formation of an intermediate layer formed on said substrate.

34. A method as claimed in Claim 33, wherein the formation of the intermediate layer includes the formation of a buffer layer.

35. A method as claimed in Claim 34, wherein the buffer layer is formed by thermally oxidising the substrate.

36. A method as claimed in Claim 34 or Claim 35, wherein the formation of the intermediate layer further includes the formation of a lower cladding layer formed on said buffer layer.

37. A method as claimed in Claim 36, wherein the formation of the lower cladding layer includes doping said lower cladding layer with a dopant.

38. A method as claimed in Claim 37, wherein the dopant includes dopant ions.

39. A method as claimed in any of Claims 30 to 38, wherein the second core layer is formed on the first core layer and wherein the first core layer is formed on the substrate.

40. A method as claimed in any of Claims 30 to 39, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

41. A method as claimed in Claim 39, wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

42. A method as claimed in any of Claims 30 to 41, wherein the steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer comprise the steps of:
depositing each layer; and
at least partially consolidating each layer.

43. A method as claimed in Claim 42, wherein any one of the substrate, the first core layer, the second core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of the first core layer, the second core layer or the upper cladding layer.

44. A method as claimed in any of Claims 30 to 43, wherein the formation of the substrate includes the doping of the substrate with a dopant.

45. A method as claimed in any of Claims 30 to 44, wherein the dopant includes dopant ions.

46. A method as claimed in Claim 44 or Claim 45, wherein the substrate dopant includes a mobile dopant.

47. A method as claimed in Claim 45 or Claim 46, wherein said first core layer dopant ions include tin and/or cerium and/or sodium.

48. A method as claimed in any of Claims 45 to 47, wherein said second core layer dopant ions include a rare earth and/or a heavy metal and/or compounds thereof.

49. A method as claimed in Claim 48, wherein said rare earth is Erbium and/or Neodymium.

50. A method as claimed in any of Claims 30 to 49, wherein the concentration of the first core layer dopant is selectively controlled during the formation of the

first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

51. A method as claimed in Claim 50, wherein the concentrations of the first core layer dopant and second core layer dopant are controlled to give a refractive index for the waveguide core which differs from that of the substrate layer by at least 0.05%.

52. A method as claimed in any of Claims 34 to 51, wherein said lower cladding layer and said buffer layer are formed substantially in the same step.

53. A method as claimed in any of Claims 42 to 52, wherein at least one of the substrate, the first core layer, the second core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

54. A method as claimed in Claim 53, wherein the Chemical Vapour Deposition process is a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

55. A method as claimed in any of Claims 42 to 54, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

56. A method as claimed in any of Claims 42 to 55, wherein the consolidation is by fusing in a furnace.

57. A method as claimed in Claim 55 or Claim 56, wherein the step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer are performed simultaneously.

58. A method as claimed in any of Claims 30 to 57, wherein the waveguide core is formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process.

59. A method as claimed in Claim 58, wherein the dry etching technique comprises a reactive ion etching process and/or a plasma etching process and/or an ion milling process.

60. A method as claimed in any of Claims 30 to 59, wherein the waveguide core formed from the first core layer and the second core layer is square or rectangular in cross-section.

61. A method according to any of Claims 30 to 60, wherein the first core layer is doped with at least 17%wt germanium dopant.

62. A laser waveguide with multiple core layers for transmitting an optical signal, the laser waveguide comprising a waveguide as claimed in any of claims 1 to 29, the laser waveguide further comprising:

at least one grating formed in said waveguide core.

63. A laser waveguide as claimed in Claim 62, wherein the laser waveguide further comprises at least one optical interference mirror.

64. A laser waveguide as claimed in Claim 63, wherein the optical interference mirror is provided at the input of the waveguide.

65. A laser waveguide as claimed in Claim 64, wherein the interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

66. A laser waveguide as claimed in any of Claims 62 to 65, wherein the laser waveguide includes two mirrors and a grating.

67. A laser waveguide as claimed in any of Claims 62 to 65, wherein the laser waveguide includes one mirror and two gratings.

68. A laser waveguide as claimed in Claim 62, wherein the laser waveguide includes three gratings.

69. A laser waveguide as claimed in any of Claims 62 to 68, wherein the grating formed is a Bragg grating.

70. A laser waveguide as claimed in any of Claims 62 to 69, wherein said grating forms an output coupler for said laser waveguide.

71. A laser waveguide as claimed in any of Claims 62 to 70 further comprising an optical interference mirror butt coupled to or directly deposited at the output of the waveguide.

72. A method of fabricating a laser waveguide, comprising forming a waveguide according to a method as claimed in any of Claims 30 to 61, the method of fabricating the laser waveguide further including the steps of: forming at least one grating in said waveguide core.

73. A method as claimed in Claim 72, further including the step of attaching at least one optical interference mirror to the waveguide.

74. A method as claimed in Claim 73, wherein the optical interference mirror is attached to an input of the waveguide.

75. A method as claimed in any of Claims 72 to 74, wherein the grating is formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide.

76. A method as claimed in Claim 75, wherein said mask is a quartz mask.

77. A method as claimed in any of Claims 72 to 74, wherein the grating is formed using a using an interference side writing technique.

78. A method as claimed in any of Claims 72 to 74, wherein the grating is formed using a direct writing technique.

79. A method as claimed in any of Claims 72 to 78, wherein the grating formed is a Bragg grating.

80. A method as claimed in any of Claims 73 to 79, wherein the optical interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

81. A method as claimed in any of Claims 72 to 79, further comprising the step of attaching a second optical interference mirror to the output of the waveguide.

82. A waveguide substantially as described herein and with reference to Figs. 1A to 1C of the accompanying drawings.

83. A laser waveguide substantially as described herein and with reference to Figs. 2A and 2B of the accompanying drawings.

84. A method of fabricating a waveguide with multiple core layers substantially as described herein and with reference to Figs. 1A to 1C of the accompanying drawings.

85. A method of fabricating a laser waveguide with multiple core layers substantially as described herein and with reference to Figs. 2A and 2B of the accompanying drawings.